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Nonperturbative theory of atom-surface interaction: Corrections at short separations

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Abstract

© 2018 IOP Publishing Ltd. The nonperturbative expressions for the free energy and force of interaction between a ground-state atom and a real-material surface at any temperature are presented. The transition to the Matsubara representation is performed, whereupon the comparison is made with the commonly used perturbative results based on the standard Lifshitz theory. It is shown that the Lifshitz formulas for the free energy and force of an atom-surface interaction follow from the nonperturbative ones in the lowest order of the small parameter. Numerical computations of the free energy and force for the atoms of He- and Na interacting with a surface of an Au plate have been performed using the frequency-dependent dielectric permittivity of Au and highly accurate dynamic atomic polarizabilities in the framework of both the nonperturbative and perturbative theories. According to our results, the maximum deviations between the two theories are reached at the shortest atom-surface separations of about 1 nm. Simple analytic expressions for the atom-surface free energy are derived in the classical limit and for an idealmetal plane. In the lowest order of the small parameter, they are found in agreement with the perturbative ones following from the standard Lifshitz theory. Possible applications of the obtained results in the theory of van der Waals adsorption are discussed.

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Keywords

atom-surface interaction, Lifshitz formula, nonperturbative theory

References

[1] Parsegian V A 2005 Van der Waals Forces: a Handbook for Biologists, Chemists, Engineers, and Physicists (Cambridge: Cambridge University Press)
[2] London F 1930 Z. Phys. 63 245
[3] Lennard-Jones J E 1932 Trans. Faraday Soc. 28 333
[4] Casimir H B G and Polder D 1948 Phys. Rev. 73 360
[5] Passante R, Rizzuto L, Spagnolo S, Tanaka S and Petrosky T Y 2012 Phys. Rev. A 85 062109
[6] Casimir H B G 1948 Proc. K. Ned. Akad. Wet. 51 793
[7] Lifshitz E M 1955 Zh. Eksp. Teor. Fiz. 29 94
[8] Lifshitz E M 1956 Sov. Phys. JETP 2 73
[9] Dzyaloshinskii I E, Lifshitz E M and Pitaevskii L P 1961 Adv. Phys. 10 165
[10] Dzyaloshinskii I E, Lifshitz E M and Pitaevskii L P 1961 Usp. Fiz. Nauk 73 381
[11] Lifshitz E M and Pitaevskii L P 1984 Statistical Physics (Oxford: Pergamon)

[12] Bordag M, Klimchitskaya G L, Mohideen U and Mostepanenko V M 2015 Advances in the Casimir Effect (Oxford: Oxford University Press)
[13] Babb J F, Klimchitskaya G L and Mostepanenko V M 2004 Phys. Rev. A 70 042901
[14] Antezza M, Pitaevskii L P and Stringari S 2004 Phys. Rev. A 70 053619
[15] Caride A O, Klimchitskaya G L, Mostepanenko V M and Zanette S I 2005 Phys. Rev. A 71 042901
[16] Buhmann S Y, Knöll L, Welsch D-G and Dung H T 2004 Phys. Rev. A 70 052117
[17] Buhmann S Y and Welsch D-G 2007 Prog. Quantum Electron. 31 51
[18] Bezerra V B, Klimchitskaya G L, Mostepanenko V M and Romero C 2008 Phys. Rev. A 78 042901
[19] Safari H, Welsch D-G, Buhmann S Y and Scheel S 2008 Phys. Rev. A 78 062901
[20] Buhmann S Y, Safari H, Dung H T and Welsch D-G 2007 Opt. Spectrosc. 103 374
[21] Bimonte G, Klimchitskaya G L and Mostepanenko V M 2009 Phys. Rev. A 79 042906
[22] Shimizu F 2001 Phys. Rev. Lett. 86 987
[23] Friedrich H, Jacoby G and Meister C G 2002 Phys. Rev. A 65 032902
[24] Druzhinina V and DeKieviet M 2003 Phys. Rev. Lett. 91 193202
[25] Harber D M, McGuirk J M, Obrecht J M and Cornell E A 2003 J. Low. Temp. Phys. 133 229
[26] Leanhardt A E, Shin Y, Chikkatur A P, Kielpinski D, Ketterle W and Pritchard D E 2003 Phys. Rev. Lett. 90 100404
[27] Lin Y-j, Teper I, Chin C and Vuletić V 2004 Phys. Rev. Lett. 92 050404
[28] Obrecht J M, Wild R J, Antezza M, Pitaevskii L P, Stringari S and Cornell E A 2007 Phys. Rev. Lett. 98 063201
[29] Lattuca M, Marino J, Noto A, Passante R, Rizzuto L, Spagnolo S and Zhou W 2017 J. Phys.: Conf. Ser. 880 012042
[30] Bartolo N, Butera S, Lattuca M, Passante R, Rizzuto L and Spagnolo S 2015 J. Phys.: Condens. Matter 27 214015
[31] Bezerra V B, Klimchitskaya G L, Mostepanenko V M and Romero C 2010 Phys. Rev. D 81 055003
[32] Bezerra V B, Klimchitskaya G L, Mostepanenko V M and Romero C 2014 Phys. Rev. D 89 035010
[33] Chaichian M, Klimchitskaya G L, Mostepanenko V M and Tureanu A 2012 Phys. Rev. A 86 012515
[34] Klimchitskaya G L and Mostepanenko V M 2014 Phys. Rev. A 89 012516
[35] Klimchitskaya G L and Mostepanenko V M 2014 Phys. Rev. A 89 062508
[36] Ribeiro S and Scheel S 2013 Phys. Rev. A 88 042519
[37] Ribeiro S and Scheel S 2014 Phys. Rev. A 89 039904
[38] Nichols N S, Del Maesto A, Wexler C and Kotov V N 2016 Phys. Rev. B 93 205412
[39] Bordag M 2017 Phys. Rev. A 96 062504
[40] Ford G W, Lewis J T and O'Connell R F 1985 Phys. Rev. Lett. 55 2273
[41] Berman P R, Ford G W and Milonni P W 2014 Phys. Rev. A 89 022127
[42] Ciccarello F, Karpov E and Passante R 2005 Phys. Rev. A 72 052106
[43] Bordag M 2017 Theor. Math. Phys. in preparation arXiv:1707.06214v
[44] Yan Z-C and Babb J F 1998 Phys. Rev. A 58 1247
[45] Pérat M, Caffarel M and Pouchan C 1993 Phys. Rev. A 48 161
[46] Derevianko A, Johnson W R, Safronova M S and Babb J F 1999 Phys. Rev. Lett. 82 3589
[47] Palik E D (ed) 1985 Handbook of Optical Constants of Solids vol 1 (New York: Academic)
[48] Klimchitskaya G L, Mohideen U and Mostepanenko V M 2009 Rev. Mod. Phys. 81 1827
[49] Decca R S, Fischbach E, Klimchitskaya G L, Krause D E, López D and Mostepanenko V M 2003 Phys. Rev D 68 116003
[50] Decca R S, López D, Fischbach E, Klimchitskaya G L, Krause D E and Mostepanenko V M 2005 Ann. Phys., NY 318 37
[51] Decca R S, López D, Fischbach E, Klimchitskaya G L, Krause D E and Mostepanenko V M 2007 Phys. Rev. D 75 077101
[52] Decca R S, López D, Fischbach E, Klimchitskaya G L, Krause D E and Mostepanenko V M 2007 Eur. Phys. J. C 51 963
[53] Chang C-C, Banishev A A, Castillo-Garza R, Klimchitskaya G L, Mostepanenko V M and Mohideen U 2012 Phys. Rev. B 85 165443
[54] Banishev A A, Klimchitskaya G L, Mostepanenko V M and Mohideen U 2013 Phys. Rev. Lett. 110 137401
[55] Banishev A A, Klimchitskaya G L, Mostepanenko V M and Mohideen U 2013 Phys. Rev. B 88 155410
[56] Bimonte G, López D and Decca R S 2016 Phys. Rev. B 93 184434

[57] Mostepanenko V M 2015 J. Phys.: Condens. Matter 27 214013
[58] Klimchitskaya G L, Mohideen U and Mostepanenko V M 2012 J. Phys.: Condens. Matter 24 424202
[59] Klimchitskaya G L and Korikov C C 2015 J. Phys.: Condens. Matter 27 214007
[60] Klimchitskaya G L and Mostepanenko V M 2017 J. Phys.: Condens. Matter 29 275701
[61] Chen Y-J, Tham W K, Krause D E, López D, Fischbach E and Decca R S 2016 Phys. Rev. Lett. 116 221102